

## TREE MODELING IN HORTICULTURAL CROPS: A REVIEW

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Agriculture is the integral part of the world's economy with major share of horticulture; however, excessive use of chemicals in industry and agriculture, polluted the natural resources which could be reduced through tree modeling. Changing climate is not only impeding the competent utilization of farm inputs but also ensure to improve human health. Tree modeling is the comprehensive revision of crop phenology associated with shifting climate. It forecast the specific behavior of plants in shifting climate with its various forms i.e. phenological models of numerous plant systems, water models, nutrition and nitrogen dynamic models etc. Models are developed through excessive studies of crop behavior, soil profile, climate and GIS data. Moreover, genomic studies also support the genotype behavior and its adoptability in fluctuating climate. The mathematical, meteorological and agri-engineering equations are developed to establish correlation between crop and environment based on excessive plant physiological and environmental data. In this review article, importance of modeling, Critical phenological growth stages in fruit plants, physiology of plant respiration, photosynthesis and path of nutrients and water uptake by plants is discussed in detail.

**Keywords:** Climate change, global warming, precision agriculture, remote sensing, tree phenology, degree days, crop productivity, ecosystem, carbon skeleton, radiation geometry, source-sink relationship.

### INTRODUCTION

Nature has control over all sorts of climate change and phenological events in living organisms including Plants. Phenological studies become more important for growers because of shifts in seasonal timing to schedule the cultural practices (Menzel *et al.*, 2006 a,b). Phenology is the initiation or termination of a specific growth stage in response to climate while tree modeling is the simulation of plant phenological stages based on temperature, photoperiod and precipitation which are the key aspects to adjust cultural practices in changing climate scenario (Menzel, 2003). Tree modeling can truly predict plant growth and developmental processes like flowering, fruit set, growth, development, maturity and harvest timing and thus time resources and income saved. Phenological models can accurately inform the farmers about the crop condition during growing season and thus improve efficacy and timing of pesticide, fertilizer, irrigation and scheduling the harvest operations (Chmielewski, 2003). Improving the time of input applications, decreases the number of pesticide application and ultimately reduce the cost of production and environmental pollution. In addition, crop phenology has recently become a key component of climate change impact

research. Biological, technical and economic models are useful as complementary tools to support decision-making in agriculture. Biological models required a high range of criterion for rapid adaptation over the evaluation and exploration (Boiffin *et al.*, 2001).

Tree model is a certain process or arrangement developed by quantitative mathematical equations as key variables controlling the process. There are rule-based and image-based modeling techniques in which former is the set of generative rules or grammar to create branches and leaves, represented as L-system unfolding the fractal objects (Lindenmayer, 1968). Modeling (L-system) is carefully studied and implemented to different versions, e.g. the parametric L-system and the differential L-system (Prusinkiewicz *et al.*, 1994). Rule-based techniques provide solid control on the form of trees and create light-weight tree models with expertise in botany to adjust the parameter values and are engineered as natural trees. In image-based techniques and tree geometries are directly recovered by various range of photographs and models are constructed using these images (Shlyakhter *et al.*, 2001; Reche-Martinez *et al.*, 2004). These techniques are highly intelligent and assure reality of the models because these models are reconstructed from real images. However, it is inconvenient for users to change the

tree models due to huge amount of data. Drawback of these techniques are resolved through combining rule-based and image-based techniques and established light weight 3D tree models. In this model, 3D skeleton of a tree trunk and the branching structure could be reconstructed from images using binocular vision methods and the parametric L-system with its large-scale web virtual forest applications. Though it is light weight, economical and photorealistic yet the reconstructed trunk, recovered branches and extracted L-system rules and parameters are unsatisfactory in precision, efficiency and robustness. Conceptual understanding of the involved physiological processes, imaginative, quantitative thinking and extensive agricultural/biological database is the pre-requisite in tree modeling.

**Significance of tree modeling:**

Uncertain climatic change (global warming) is drastically shifting time of phenological stages of all organisms especially plants like bud differentiation, bud break, flowering, fruit set, growth and development (Menzel *et al.*, 2006a; Van Buskirk *et al.*, 2009; Parmesan, 2006; Bertin, 2008). Current temperature of the world is 2-3°C higher than 50 years ago which advancing the time of spring events and shifting the phenological stages along with the length of growing season (Miller-Rushing and Primack, 2008; Menzel *et al.*, 2006a; Miller-Rushing *et al.*, 2006). Temperature is pre-dominant climatic factor affecting various critical growth stages including flowering time (Fitter *et al.*, 1995) and extending its effect on various worldwide ecosystems (Estrella and Menzel, 2006; Lu *et al.*, 2006; Menzel *et al.*, 2006a; Gordo and Sanz, 2005). Moreover, precipitation, soil nutritional level and photoperiod also have significant impact on tree phenology (Badeck *et al.*, 2004). Changing climatic conditions and shifting of spring timing has changed the onset and duration of various critical phenological events in citrus. Therefore, phenological growth stages should be recorded and correlated with climate change to simulate phenological stages with temperature change. Thus, the time of cultural practices (irrigation and nutrients application) may be forecasted accurately to higher the efficiency and enhance production and fruit quality in changing climate Scenario of the world.

Early attempts in prediction of phenological events require to study the relationship between environment and crop productivity. Crop weather relationship was simulated in models for forecasting phenological events to improve the efficacy of cultural practices (Chmielewski, 2003). Biometeorological calendars, growing degree days (GDD), stress degree days (SDD) and energy-crop growth (ECG) have been introduced to develop crop models (Ben Mechlia and Carrol, 1989). Iglesias (2007) reviewed the simulation of fruit development in citrus and proposed it as a model for forest and fruit plants (Talon and Gmitter, 2008) dealing with genomic tools and Tadeo *et al.* (2008) who studied the molecular biology and genetics in citrus. Fruit maturation

stages and heat-unit data has strong positive correlation and used as blooming simulation in citrus (Davenport, 1990), mango (Davenport and Nunez-Elisea, 1997), Lychee (Menzel, 1984) and almond (Degrandi *et al.*, 1996).

**Limitations in plant modeling:**

Plant productivity models consist of sub models of growth, soil biology and plant phenology, influenced by meteorological factors and change in plant phenological phases which also affect plant growth, water and carbon cycles within the ecosystem (Van Wijk *et al.*, 2003). Extensive research proved that plant phenological stages excessively influenced by ecosystem. Penuelas and Filella (2001) considered these changes as sensitive and observable as global warming in the biosphere. Modeling is mainly affected by soil and climate which in turn affect the rate of photosynthesis, bud differentiation, flowering, fruit growth, development, harvesting and crop yield etc.

It is critical to understand the limitations of any developed crop model during its use since they are necessarily gross simplifications of complex systems. A model with all key processes behaves realistically but they become too difficult to understand and errors become more difficult to elucidate. Unavailability of extensive data base is major limiting factor in the development of fruit tree model. Root growth pattern and its turnover rate, respiration and its implications are major gap in tree modeling. Response to temperature is limited by short term phenological data. Moreover, measurement of seasonal demand of carbon in different plant organs and detailed data of fruit abscission process minimize the accuracy of tree modeling. The canopy management is unique challenge in tree modeling. Publication of crop models is difficult because scientific journals usually discourage the extensive length and discussion needed to fully explain the assumptions, characteristics and limitations of crop models. The accessibility of crop models in management decisions of horticultural practices is difficult. Usually researchers lack strong mathematical and programming skills and computer programming to run tree model.

**Topographies of fruit tree models:**

Carbon supply and consumption budget has provision of an overall quantitative description of fruit trees annual production through equation of carbon supply and consumption:

$$P_n + S_{to} = S_r + R_r + D_r + F_n.w.r + P_r + S_{to}$$

where  $P_n$ : photosynthetic production;  $S_{to}$ : nonstructural carbon reserves;  $S_r$ : current year's shoot mass [including leaves and stem], multiplied by a respiratory quotient;  $R_r$ : current year's root mass, multiplied by a respiratory quotient;  $D_r$ : current year's drop of flowers and fruitlets, multiplied by a respiratory quotient;  $F_n.w.r$ : fruit number multiplied by fruit weight and respiratory quotient;  $P_r$ : perennial organ mass, multiplied by a respiratory quotient.

This expression is simple and detailed enough to indicate major parameters that yet need to determine experimentally.

**Photosynthesis and tree modeling:**

A central feature of crop models is the estimation of photosynthesis that provides energy and carbon skeleton for various biological processes. Photosynthesis evaluation is done by three ways.

Light intensity gradient and photosynthesis is calculated by leaf area at given level of light in various time intervals of minutes to hours and summed for daily total of photoperiod. Due to the movement of sun, radiation geometry and type of canopy must be included in calculation. In orchards with rows of discontinuous canopies and consequently significant lateral radiation fluxes, the role of diffuse of light in canopy photosynthesis should be considered (Allen *et al.*, 1974). This is especially true with thin vertical canopies typical of vineyards and some orchards where an entire side of the canopy may receive only diffuse radiation.

“Big leaf model” is used to estimate canopy photosynthesis as a daily canopy light response to daily intercepted radiation based on incident radiation and fractional interception using Beer’s law and exposed leaf photosynthesis (Charles-Edwards, 1982). This approach snubs the gradients of light and photosynthesis in leaf of different populations and varying radiation geometry. These approaches require photosynthesis data and canopy loss coefficients; however, daily big leaf model requires only daily radiation data. Daily fractional light interception from direct measurements entered to further simplify the model and successfully used in apple dry matter production model (Lakso and Johnson, 1990; Lakso *et al.*, 2001).

A new approach to plant and crop with very concise programming language called “L-Systems” (Prusinkiewicz, 2004) based on plant growth pattern was established by Aristid Lindenmayer (botanist). It can calculate light interception and canopy photosynthesis as well as many other processes, initially used to model a peach tree (Allen *et al.*, 2002).

**Respiration cost:**

Estimates of respiration cost (maintenance respiration and growth respiration) are required in carbon-based crop models. It is estimated with empirically-determined specific respiration rate per unit organ, multiplied by total number of same type of organs. Maintenance and growth respiration are usually modeled separately as partitioning may vary between growth and maintenance. Maintenance and growth respiration cannot be separated experimentally, although, several methods had developed to distinguish them (Amthor, 1989). Moreover, specific patterns of fruit respiration have received attention in different fruit crops (Walton and DeJong, 1990; Blanke and Whiley, 1995; Bustan, 1996) and most fruits have higher specific respiration early in development during cell division and lower rates as cell expands.

**Relationship of source sink:**

Source-sink relation is explained as supply–demand interaction in orchard plants. A tree may compensate source

limitations by increasing photosynthetic rates (Layne and Flore, 1992). There are following two situations regarding supply demand in fruit plants:

**High source condition:**

Under this condition each sink receives its share according to its potential growth rate. The growth of each sink depends on its genetic makeup, instead of the availability of photosynthates; however, excessive carbohydrates may inhibit photosynthetic activity in leaves (Neales and Incoll, 1968), thus photosynthesis is reduced in girdled and fruitless branches (Bustan, 1996). This feedback control is not easily determined in whole tree under field conditions as there may be alternate sinks (especially roots). This feedback control exists in fruit plant organs successfully incorporated to develop models (Lescouret *et al.*, 1998).

**High sink condition:**

Under this condition, plant must ‘decide’ the partitioning of available photosynthates among sinks, which create partitioning priority issues, faced by plant productivity modular (Marcelis *et al.*, 1998); however, priority scheme is generally based on theoretical assumptions and seldom on experimental evidence. There are two kind of partitioning modes predicted in plants, one is ‘Hierarchical mode’, assuming predetermined organ priorities (Gutierrez *et al.*, 1985) and other is ‘Proportional mode’ in which every organ gets a fixed portion of photosynthate supply based on its relative sink strength. Proportional mode of partitioning might be valid under certain circumstances whereas hierarchical partitioning mechanisms are necessary for the emergence and development of new plant organs (Bustan and Goldschmidt, 1999).

**Reproductive development:**

The long chain of developmental stages may be divided into 3 main steps consist on flowering, fruit set and its development (Goldschmidt and Monselise, 1977). The regulation of flower bud differentiation is complex and vary even within species, controlled by the concentration of carbohydrates (Goldschmidt *et al.*, 1985) and hormones (Goldschmidt and Samach, 2004); however, temperature effect on time and duration of anthesis only. Thus, dry matter productivity models do not consider the availability of carbohydrates in flower formation. In fruit set ‘initial set’ represents fruit retained at the end of anthesis after petal fall and ‘final set’ represents fruit remained after June drop (Goldschmidt and Monselise, 1977), which shows that modeling in fruit set process is not a simple task. Generalization in modeling of reproduction process is almost impossible due to endless variations in pollination compatibility, parthenocarpic potential and hormonal effects. Moreover, fruit set in most fruit species (temperate zone and subtropical) occurs during late spring (April to May in the northern hemisphere), a period with extremely unstable weather. Cold spells and dry heat waves may severely interfere with reproductive processes in cool and warm zones,

respectively; however, Gomez-Cadenas *et al.* (2000) reported that carbohydrate level determine the extent of fruitlet abscission. Lakso *et al.* (2001) developed a fruitlet abscission model based on the observations of Bepete and Lakso (1998), which proved that abscission occurs if early fruit growth rate is not maintained above a critical level and carbohydrate supply determines the fruit growth rates. This model gives realistic behavior in relation to several environmental and management factors, suggesting that carbon balance is a critical factor in apple fruit abscission. Fruit enlargement phase generally occurs in mid and late season and accessible in modeling approach tested in most fruit tree models. Fruit size is dependent upon the availability of photosynthates, as demonstrated in girdling and fruit thinning experiments (De Jong and Grossman, 1995; Fisher *et al.*, 1983; Goldschmidt, 1999) as well as foliar pest effects (Francesconi *et al.*, 1996). Growth during cell expansion phase is determined by cell numbers limited by carbon supply and genetic makeup (Goffinet *et al.*, 1995). Therefore, there may be early-season effects of carbon balance (fruit abscission and size potential) that is manifested for entire season. For modeling fruit growth demand can be estimated from the curves of fruit weight over time, where there is no sink limitation. Extreme thinning and girdling combinations have resulted in high fruit weight of 705 and 330 g, respectively in grapefruit (Bustan *et al.*, 1995; Goldschmidt, 1999); however, further fruit growth is limited by cell numbers acquired during early stage of fruit development. Details of different models in horticultural crops are discussed in upcoming reading of this manuscript.

#### **Plant water requirement models:**

Maintenance of an adequate water supply is crucial for high productivity in horticultural crops because it is necessary to maintain normal physiological activity, membrane transport processes, long-distance transport of nutrients and growth regulatory compounds in vascular system. In some situations, the cooling effect of transpiration can be an important factor allowing horticultural crops to grow in warm climate. Water is major component enriched with nutrients and maintains freshness and perishability in horticultural crops. The controlled drought could be used to stimulate flowering in guava or litchi, or it could be used as substitute for adequate chilling in temperate fruit crops such as apple grown in temperate climate (Chaikiattiyos *et al.*, 1994). Sensors are available for automatic measurement of soil or crop water status; precise definitions of various measures of water status are commonly used in horticultural sciences. Appropriate models need to account water uptake by soil, transport in plant and evaporation in atmosphere. Models developed for cell water relations essential to predict its effects on water status. Models therefore provide useful tool to predict crop water status and are suited for incorporation into standard irrigation scheduling and auto-mated irrigation control systems (Giacomelli *et al.*, 1994) especially those involving decision support systems with the ability to predict consequences of

possible management decisions e.g. irrigation scheduling. The available techniques include psychrometric changes in fruit dimension (Higgs and Jones, 1984; Johnson *et al.*, 1992; Huguet *et al.*, 1992), leaf thickness (Malone, 1992), stem diameter (Simonneau *et al.*, 1993) and gamma radiation transmission (Brough *et al.*, 1986). Inappropriately these models are difficult to operate in greenhouse or field. Jones (1992) detailed that pressure chamber used as locus instrument by researchers to monitor the status of plant water which tend to be the labor intensive and damaging.

Semi permeable membrane expresses the osmotic potential; however, soil and phloem tubes are responsible for water transport depending on gradient of sum of pressure and gravitational potentials instead of osmotic potential. Rate of photosynthesis is linked with turgor pressure or cell size instead of absolute water potential (Jones, 1992; Sinclair and Ludlow, 1985). Water plays a key role in cell expansion and growth whereas, cell and tissue growth are particularly sensitive to water deficits (Hsiao, 1973) and control of growth is largely through changes in rheological properties rather than direct changes in turgor pressure (Shackel *et al.*, 1987; Passioura and Fry, 1992). Probably these parameters are at partial control of a signal originating from roots (Gowing *et al.*, 1990; Passioura, 1988) in which ABA has an appreciable contribution (Saab *et al.*, 1990; Zhang and Davies, 1990). Water deficiency not only effects on leaf expansion but also reduce the growth in peach (Steinberg *et al.* (1990).

Water is the main constituent in developing the growth models in fleshy fruits as it largely depends on net rate of water accumulation in vascular system along with the assimilates (Ho *et al.*, 1987; Jones and Samuelson, 1983). Various semi-mechanistic fruit growth models have been projected which uptake water and nutrients through xylem and phloem and maintain the transpiration losses from soil surface. In all water models, water flow in fruit depends on its potential difference (Johnson *et al.*, 1992; Lee, 1989), yet, the rate of water flow is much slow between other plant parts for high hydraulic resistance developed in fruit peduncle.

Models of plant water relations are essential components of all crop models because growth, productivity and quality of horticultural crops are closely linked to water status. In addition to their use as components of more general crop models, models specifically relating to aspects of plant water relations have several uses to growers and their advisors as well as to the breeders of horticultural crops. Models of evaporation, water flow and stomatal conductance replace the details of soil water status. These models provide the information for irrigation schedule for field (Thompson *et al.*, 1982) and glass house crops as they are incorporated in wider decision support systems to help growers in the management of their crop growing systems (Giacomelli *et al.*, 1994; Hamer, 1991) in changing climate scenario and water scarcity.

**Plant nutrition models:**

Plants acquire all its tissue constituents from their aerial and root environment. Soil fertility and uptake of mineral nutrients governs the plant growth. Mineral nutrition is main factor limiting the plant growth, so high fertilizer inputs are necessary to produce large quantities of plant biomass (Mengel and Kirkby, 1987). Moreover, there are fixed and non-fixed factors which limit the plant growth and production. Fixed factors are CO<sub>2</sub> concentration, light, temperature and soil type, while non-fixed factors are irrigation, fertilizer application, crop protection measures, nutritional value, plant density, time of sowing, genotype and yield (Mohr and Schopfer, 1995). Estimation of nutrient availability in plant growth is confirmed through soil substrate testing depending on agro system or plant sap analysis. In hydroponic technology, sensors are used to control pH and electrical conductivity (EC) for the estimation of water and specific nutrient requirement at different phenological stages of the crop. In orchards, measurement of minute changes in stem diameter can be used to manage irrigation and nutrient distribution as well as their uptake capacity; Moreover, distribution and architecture of roots are required to develop plant nutrient model (Habib *et al.*, 1991). Plant regulate their tissues mineral composition against electrochemical gradients through active and passive processes. Ion uptake has been dedicated to characterizing plant ability to extract nutrients from the soil solution. Whole-plant testing is widely used because it gives a direct measurement of the actual quantities of nutrients taken up by the plant. When testing is not possible on the entire plant, analysis of individual organ (leaf, fruit, and petiole) is taken as a substitute. In such cases, measurements are compared with 'reference' material obtained from plants grown under non-limiting nutrient supply. The increasingly widespread use of leaf analysis has resulted in exhaustive compilations of 'normal, deficient or toxic' nutrient concentrations in plants (Chapman, 1966). During plant growth, nitrogen concentration in plant tissues may be compared to the critical nitrogen concentration thus,

Nitrogen nutrition index (NNI) =  $\%N / \%N_{critical}$

If NNI is greater than 1, crop growth is not limited by nitrogen availability in the root environment and vice versa. In this case, NNI may be used as a decision-making indicator for efficient utilization of nitrogen fertilizer. This approach also provides a ubiquitous rationale for diagnostic that may probably be extended to minerals other than nitrogen (Bot *et al.*, 1998). Most ions (K<sup>+</sup>, Na<sup>+</sup>, Ca<sup>2+</sup>, Cl<sup>-</sup>, NH<sup>4+</sup>, NO<sup>3-</sup>, PO<sub>4</sub><sup>2-</sup>, SO<sub>4</sub><sup>2-</sup>) uptake is the net result between simultaneous influx from the solution to the roots and efflux from the roots to the solution, being considered independent (Clarkson, 1986; Aslam *et al.*, 1996).

**Plant phenological models:**

Crop phenological models are preliminarily required in efficient utilization of crop inputs which directly or indirectly

reduce soil and environmental pollution with good effect on human health. These models forecast about crop growth stage, fruit growth and development stage which improve efficacy and timing of pesticide and fertilizer application and schedule the irrigation and crop harvest operations (Chmielewski, 2003), which thus reduce the production cost and environmental hazards. Plant and crop phenology have become a key component of climate change impact research (Menzel, 2003). The timing of specific flower bud stages can be used as a climatological indicator at the regional level and contribute to the evaluation of possible impact of climate change.

**Modeling in fruit trees:**

Fruit tree is a very complex organism, require careful study to develop models. Sugar beet was among the first crop plants to be modeled. It has just two major organs; a rosette type crown of leaves (source) and a storage root (sink) and is therefore relatively easy to model. Annual crop plants (soybean, cotton) are more complex having leaves, shoots, roots and reproductive structures with entire lifespan of a few months; however, fruit trees are still more complex having perennial trunk, branches and scaffold roots of several ages, in addition to a very large number of current year vegetative and reproductive organs. Developing multiple year models is very difficult as many of the important carry-over effects on plant growth are not well understood, furthermore, they are distinguished by discontinuous canopy structures, strong management via pruning and training, manipulation of crop levels and rootstock effect on scion could not understand fully in short period of time. There is a perennial woody skeleton which not only grows and develops during the annual cycle but also accumulates and exports carbohydrates and other reserve materials which complicates the estimation of net increase in biomass of a fruit tree during annual cycle. Optimizing the final size and especially quality of crop depends on a quite precise regulation of the final fruit numbers and thus growers attempt to control fruit numbers with mechanical or chemical thinning. These attempts disrupt normal processes in crops and make modeling difficult. Finally, Natural or artificially induced regulation of fruit abscission is an extremely complex process in fruit modeling. Many current and carry-over physiological effects interact with grower management and highly variable weather conditions during blooming and fruit abscission. Unfortunately, due to historically low number of fruit crop physiologists and high range of different fruit trees and databases are generally much less than major annual crops.

**Modeling in citrus:** Citrus is one of the most important and widely grown fruit tree, with total global production of 106.4 million tons (FAO, 2013). Citrus fruit is produced throughout the tropical and subtropical regions of the world, where the winter temperature is adequate for tree survival and avoidance of freeze devastation and enough water with suitable soil to support plant growth and fruit production. Differentiation of

citrus floral and vegetative buds occur just at bud sprouting close to the end of the cold season (Domingo *et al.*, 2007). Citrus cultivar, plant age and environmental conditions effect on blooming intensity and abscission (Monselise, 1986) while leafy or leafless inflorescence may take a single or several flowers depending on cultivar (Goldschmidt and Huberman, 1974). Phase I is a slow growth phase mainly consist of cell division including the period between anthesis and natural fruit drop followed by a rapid cell expansion period (phase II) for four to six months (Mehouachi *et al.*, 1995). Moreover, phase I and II coincide with increase in ABA (Mehouachi *et al.*, 2005; Agusti *et al.*, 2007).

Temperature is the major factor for flower induction, and it has been well recognized in past (Valiente and Albrigo, 2004; and Nebauer *et al.*, 2006). In subtropical regions, flowering takes place after a period of bud quiescence and exposure to low temperatures and short days of winter on spring flush besides the vegetative sprouting. Releasing bud dormancy and inducing flowers is due to low temperature exposure (Southwick and Davenport, 1986; Garcia-Luis *et al.*, 1992; Tisserat *et al.*, 1990). Moreover, temperature (20°C) supplies flower bud induction depending on time of exposure (Southwick and Davenport, 1986; Garcia-Luis *et al.*, 1992). In tropical climate flowering trigger out through water deficit spell (Southwick and Davenport, 1986) and high flowering in lemon tree as a result of water stress over the cold stress (Nir *et al.*, 1972; Chaikiatyyos *et al.*, 1994) while this response is commercially used to induce off-season flowering in lemons (Davies and Albrigo, 1994).

**Modeling in avocado:** Avocado (*Persea americana* Mill.) tree phenology was first reported in late 1950's (Chandler, 1958; Venning and Lincoln, 1958) with advanced studies by (Wolstenholme, 1981; Davenport, 1982); however, first detailed conceptual model was not published until 1988 (Whiley *et al.*, 1988). A revised and expanded phenol-physiological avocado model was developed in cool, humid subtropical climate of south-east Queensland. Model quantifies seasonal growth activities of reproductive and vegetative components of tree with detailed seasonal changes in leaf nitrogen and chlorophyll contents and recorded changes in photo-assimilation efficiency of leaves from summer to spring. Pheno-physiological model has assisted in the development of disease prevention strategies and limitations in production. Model was refined with the incorporation of physiological data providing a more in-depth interpretation of tree growth and potential yield limitations. Details of this improved model are as follow:

Nitrogen concentration remained relatively stable from April to July, a period of extended quiescence in tree canopy. However, there was a sharp decline during inflorescence probably due to remobilization to support these adjacent sinks, with recovery during anthesis but declining once more during fruit set and spring shoot growth.

Net carbon dioxide assimilation of summer-flush leaves reached its highest rate in April ( $18.3 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ S}^{-1}$ ) and then slowly declined up to May. In June there was a rapid decline which remained at about  $10 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ S}^{-1}$  up to October. There was a small recovery by November followed by a rapid decline because of senescence process in leaves. Except for a lag phase going into winter the pattern of chlorophyll concentrations in leaves substantially mirrored. The autumn/winter decline can be attributed by four factors: increasing vapor pressure deficits (Schultze, 1986) end product feedback-inhibition due to increasing leaf starch concentrations (Schaffer *et al.*, 1987); low temperature photo inhibition of photo system-II (Smillie and Hetherington, 1983) and reduced leaf chlorophyll and N concentrations (DeJong, 1982; Syvertsen, 1984).

The phenol-physiological model developed for cv. 'Hass' identified seasonal interactions between vegetative (roots and shoots) and reproductive (flowers and fruit) components of tree. The offset bimodal cycle of root and shoot growth (sink phase) identified in this study, was proved to be critical with respect to timing and distribution of injected phosphonates for phytophthora root rot control in subtropical climates (Whiley *et al.*, 1995). Injection following the sink:source transition of major flush periods when roots become strong sinks are the most effective times for increasing phosphonates concentration in roots and treatment is based on key phenological events.

Most critical periods determining both yield and fruit size occurs immediately following flowering when many fruits are dropped from tree. Warm, humid subtropical climates assimilate from current photosynthesis as opposed to store the sources is critical for fruit retention and growth (Whiley, 1995). Research has demonstrated that by increasing leaf N through soil application prior to flowering in conjunction with mid-bloom foliar application of paclobutrazol (Whiley *et al.*, 1995) result in significant increase in yield of avocado cv. 'Hass'. The replacement of leaf nitrogen and suppression of new shoot growth result in higher rates in the over- winter canopy presumably increase carbon supply to developing fruits.

**Modeling in cucumber and peach:** The number of days to harvest cucumber vary as the temperature of the region fluctuates, which make it difficult to predict harvesting schedule. Prediction of growth stage and harvest date used to improve crop management include scheduling labor and machinery, input management practices of crop production and protection and timely production for high market prices (Perry and Wehner, 1996). Fruit model on peach was developed as a contribution of SMARTFRUIT work package in the framework of the EU Project, ISAFRUIT. A peach tree can be considered as the collection of fruit-bearing shoots (FBS). This model is composed of four existing process-based models that describe dry weight (DW), growth of different components of FBS, including the fruit itself, sugar

accumulation in the fruit flesh, growth in FW (g) and fruit surface conductance to water vapor diffusion. The model concerns the fruit growth stage III and runs on a daily basis. The increase in dry weight (DW) was modeled as carbon balance of FBS according to the supply and demand approach (Lescourret *et al.*, 1998). Daily available pool of C-assimilates consisted of leaf assimilation plus carbon mobilized from reserves and possibly carbon from rest of the tree. The level of carbon transfer depends on leaf-to-fruit ratio (number of leaves per number of fruit) on both the FBS and tree. Leaf photosynthesis in fruit bearing shoots (FBS) may be affected by feedback inhibition caused by leaf carbon reserves. Carbon is allocated according to organ demand and priority rules. Maintenance respiration costs, vegetative growth and reproductive growth have first, second, and third-order priorities, respectively. The carbon demand for fruit growth depends strongly on sink size and activity which means that fruit history plays an important role in fruit carbon demand.

**Conclusion:**

A fruit tree model is an attempt to describe certain processes using quantitative mathematical expression that focus on a relatively a few key variables that control the process. Environment safe decisions in agricultural practices are ensured with Biological, Economical and Technical models. In this article, the basis of fruit tree models i.e. crop physiology, biology and genetics is discussed in detail. There are rule-based and image-based models in which image-based techniques are highly intelligent and able to measure reality of models because models are reconstructed from real images by gaining the knowledge of physiology of specific processes. Modeling in horticultural crops is necessary because phenological models inform growers about crop growth and development stages during growing season. So it is useful tool for improving the efficiency and timing of application of pesticide and fertilizers, and scheduling irrigation and harvest operations. By developing water, nutrition and growth models, growers could forecast plant requirement and growth stages and reduce the cost of production and environmental hazards without compromising the production. The main issue for a modular is, how to make the model simple or complex because sometimes model behavior is unrealistic and unreliable. Water and nutrition requirement and its uptake are most important in the development of models in horticultural crops. Fruit trees require careful studies and observations to develop the models because of perennial trunks, scaffold branches and roots of several ages in addition to a very large number of current year vegetative and reproductive systems in fruit plants. The carbon supply and consumption budget, evaluation of tree photosynthesis, respiration costs, source sink relationship and partitioning priorities, reproductive development and fruit growth and the role of climate change data are different features of fruit tree models. Tree modeling

is the future of horticulture production to use natural resources with minimal disorder.

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